Environmental High Temperature Testing System

AFOSR Equipment Grant (F49620-95-1-0484)
Final Report (July 1995 - June 1997)

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Summary

AFOSR Equipmental Project, entitled "Environmental High Tempearture Testing System for Advanced Structural Materials" (High Temperature Testing System, in short) was completed March 31, 1997. The system consists of three major parts: Tension/Compression Instron 8562 system, Sinku-Riko Image Furnace System and Innova 308 Argon-Ion Laser System.

This High Temperature Testing System has several features that others do not have: fast heating/cooling by using the image furnace system, and strain measurement by laser interferometry system. Currently we are still calibrating the whole system by examining each system first, i.e., the Instron 8562 system with image furnace and laser interferometry system. The high temperature testing system is helping the PI (Taya) for his current parent AFOSR grant on thermomechanical behavior of functionally graded materials (F49620-96-1-0158), Co-PI (Kobayashi) for his AFOSR grant on failure process zone modeling (F49620-93-2-0210) and Co-PI (Jenkins) for his DOE grant on continuous fiber ceramic matrix composites (subcontract of Lockheed Martin ERC DE-AC05-840R21400).

The details of each subsystem and whole system are given in the text.

1. Introduction

A standard high temperature testing system consists of a mechanical tester surrounded by a high temperature furnace of resistance heat source which is in turn surrounded by an environmental chamber where the measurement of strains is normally done by a high temperature extensometer. The disadvantages of such a standard high temperature testing system are expensive cost of whole system, slow heating/cooling capability and large heat mass adversely affecting the grips and surrounding parts. Under the AFOSR equipmental grant we designed a new type of high temperature testing system, where the above disadvantages are eliminated, i.e., cost effectiveness, fast heating/cooling capability and keeping the grips and surrounding parts in good conditions even for high temperatures imposed on specimen gauge length area.

The high temperature testing system consists of a mechanical tester (Instron 8562 tension/compression frame with high temperature grips), high temperature vacuum furnace (Sinku-Riko infrared image furnace system with VHT-E68 model) and laser interferometry system (Innova 308 Argon Ion Laser). Schematic illustraion of the system is shown in Fig. 1.

Currently, we are still calibrating each subsystem and expect to assemble them into the whole system and use it as it is originally designed. In the main text, we shall describe the details of each subsystem.

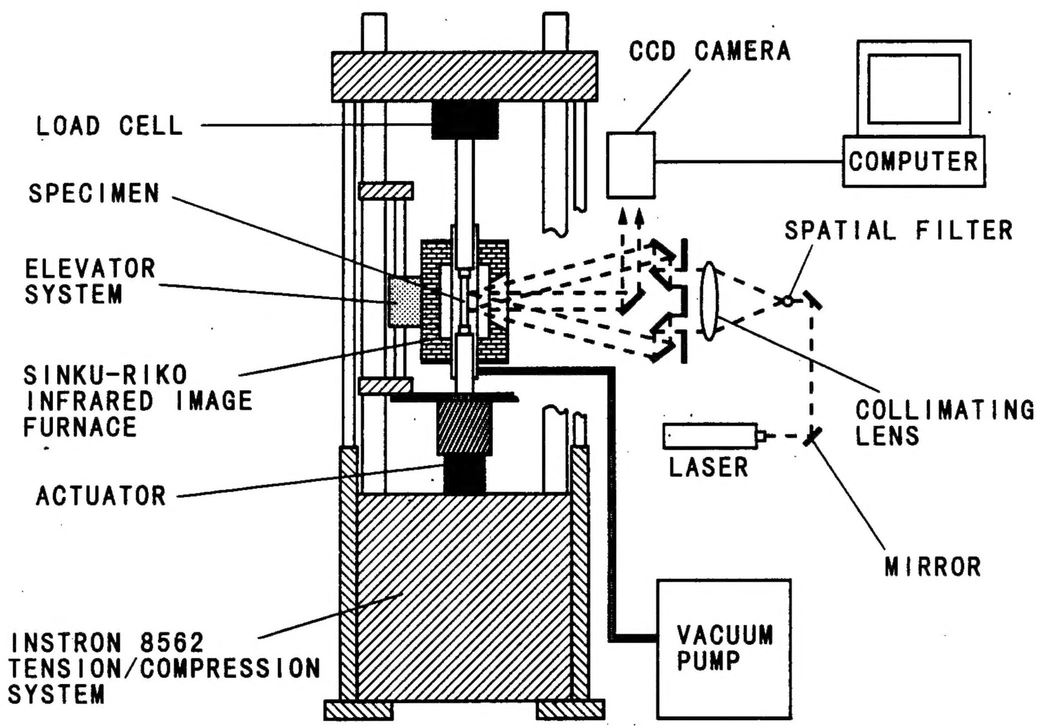
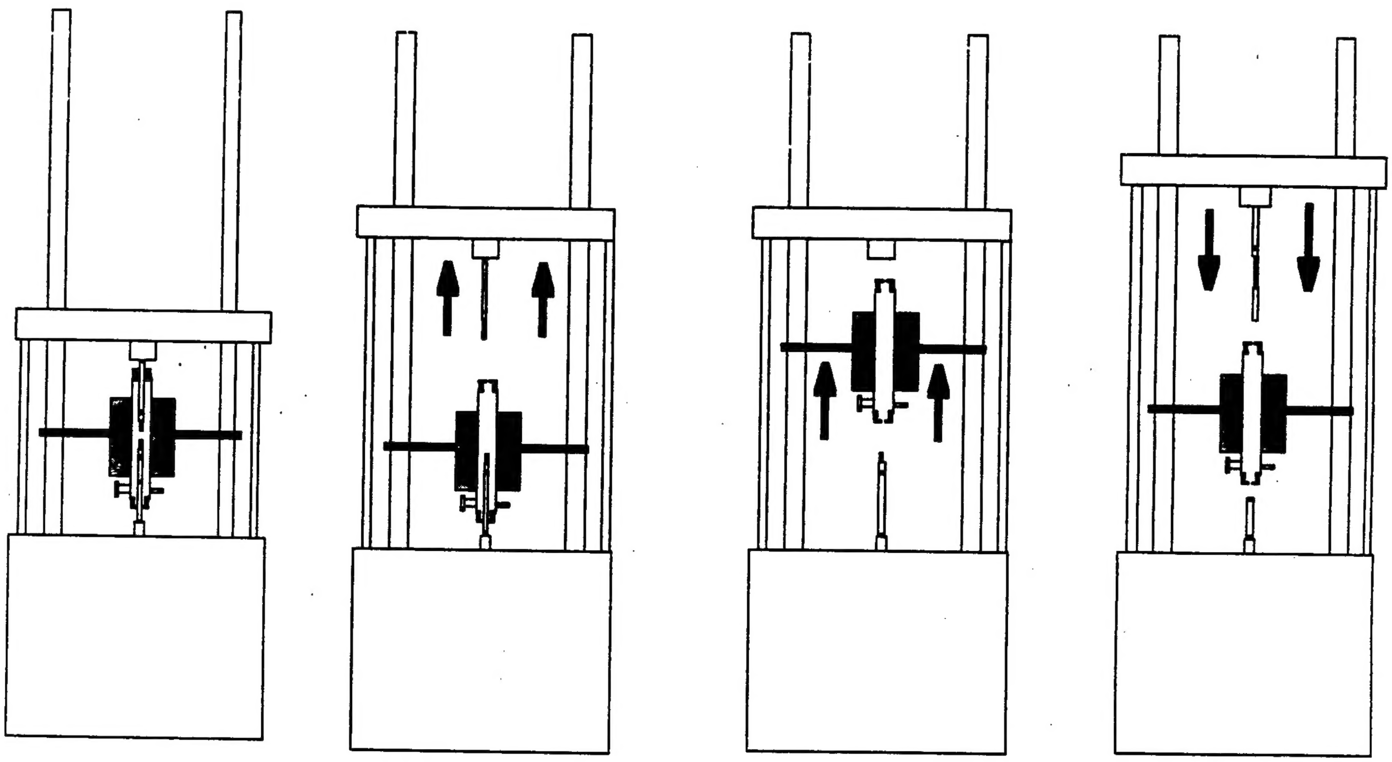


Fig. 1 High temperature testing system

2. Mechanical Tester

This Instron 5862 system has a capacity of tension/compression of 250 kN (55 Kip) with electric actuator and water-cooled high temperature grip (of 22 Kip capacity). The frame has an extra large daylight height of 93 inches to accommodate a special vacuum furnace. The sequence of mountain a specimen is schematically shown in Fig. 2 where (a), (b), (c), and (d) denote, respectively, the configuration of the testing system with specimen, moving the upper unit with upper part of a broken specimen, moving the lower unit with lower part of the broken specimen and mounting a new specimen and lowering the upper unit. This apparently cumbersome sequence stems from the fact that the specimen is surrounded by quartz tube inside which small-sized environmental chamber is located. The smallness of the environmental chamber (vacuum, inert gas, etc.) is the advantage of our design as compared with large environmental chamber common to other high temperature testing systems.



. the furnace is attached to the column through the horizontal arms with bolt.

(a)

. raise the bed and remove the upper side of the broken specimen with pull rod and grip.

(b)

. loosen the bolts of the arms .
. raise the furnace by a lift or by hands.
. remove the lower side of the specimen with pull rod and grip.

(c)

.fix the furnace at the proper location and attach the new specimen and grip to the load cell.

(d)

Fig. 2 Sequence of unloading and mounting a specimen

3. Infrared Image Furnace

The Sinku-Riko infrared image furnace has a capability of the maximum temperature 1700°C for a short time and use temperature up to 1500°C for longer times. The environment within the furnace is air, inert gas or vacuum. The heat sources are infrared tubular heating with gold plated elliptical reflectors. The effective heating area is 20 mm diameter and 200 mm long while the uniform temperature zone is 15 mm diameter and 70 mm long. The heating rate is 100°C/min. while the cooling rate depends on natural radiation of specimen itself and grip part, and can be faster by flushing cool air jet into specimen zone. The heating unit consists of 6 infrared lamp with the total power of 36 kw, supplied by electric power of 220 VAC 38 KVA and three phases. Temperature of the furnace is controlled by programmable controller (model TPC1-3-36) with P.I.D. and fudgy control.

The Sinku-Riko infrared image furnace system is to be mounted to the Instron 8562 mechanical testing system as illustrated in Fig. 3 where (a) and (b) denote the profile view with the Instron tester and details of the longitudinal cross section view, respectively, with dimensions in mm unit. Please note in Fig. 3(b) that there is an access window of laser beam for measurement of displacement of a specimen along the vertical (axial) direction and also evacuation port for vacuuming and inert gas flow.

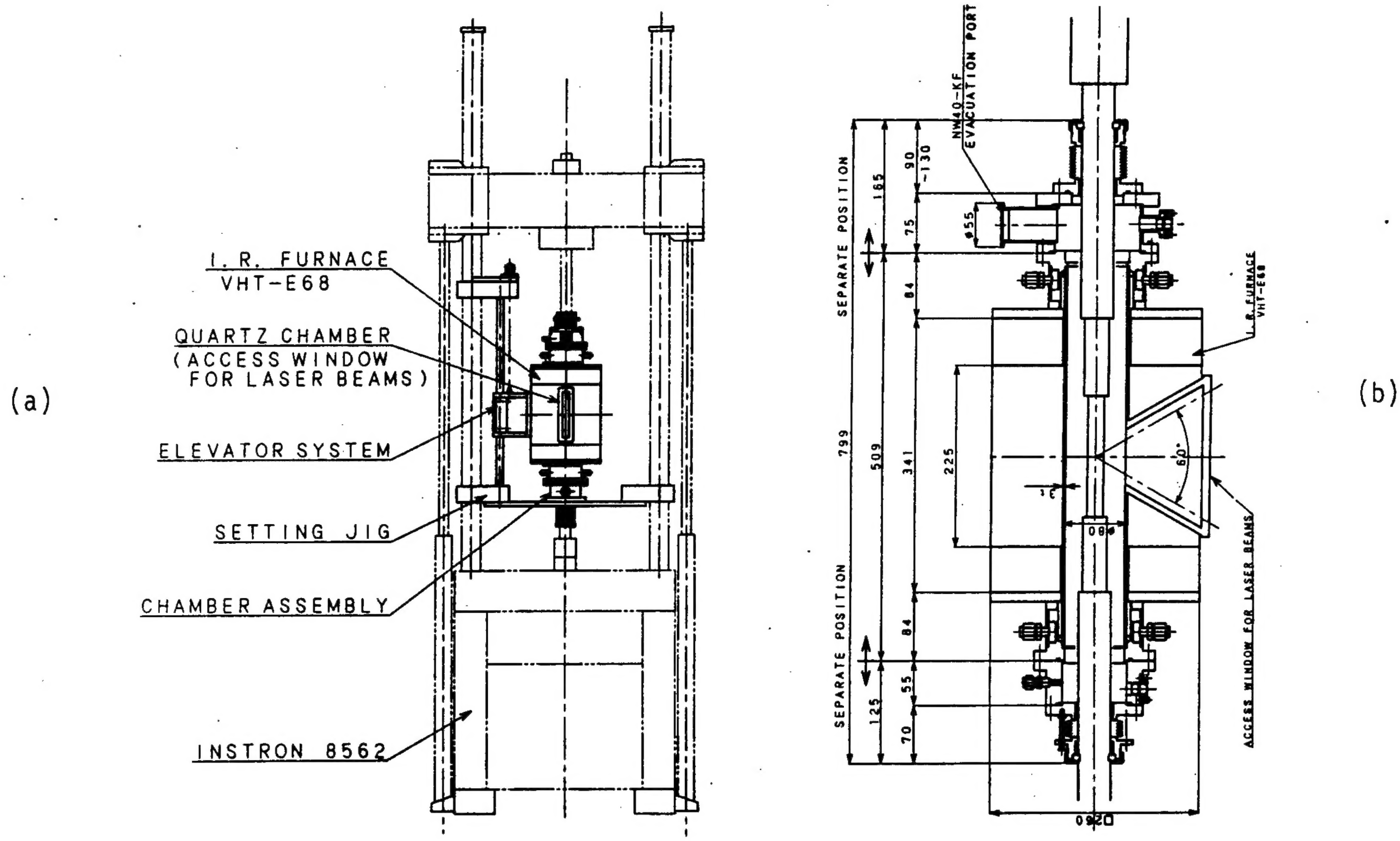


Fig. 3 Sinku-Riko Infrared Image Furnace System
(a) profile as it is mounted to the Instron 8652 tension/compression tester,
(b) magnified view of the longitudinal cross section

4. Laser Interferometry System

This system is designed to be a part of the proposed high temperature testing system, Fig. 1. Before making such a system, we first used the purchased 8 watt 308 Argon-Ion laser to create a holographic grating with a frequency of 1,200 lines per mm on a photoresist film. The process, which was developed during the past year, is to evaporate a thin nichrome film onto the polished surface of an alumina specimen, deposit a photoresist mask of 1,200 lines per mm on top of the nichrome film by interferometry technique, and then etch in ceric ammonium nitrate solution. The result is a thin nichrome grating of square dots with a frequency of 1,200 lines per mm on top of the alumina specimen. This grating can be used for Moiré interferometry, as shown by a hypothetical test setup of Figure 4, at testing temperature up to 800°C and possibly to 1000°C which is beyond the glassy phase of alumina.

The phase shifting Moiré interferometry was then used to study the fracture process zone (FPZ) in ceramics at room temperature. The phase shifting procedure provided an added order of magnitude to the sensitivity of the 1200-lines/mm Moiré grating which in itself lacked the sensitivity for analyzing the brittle alumina. The utility of the phase shifting Moiré interferometry was demonstrated by a room temperature, slow crack growth study of an alumina WL-DCB specimen, Fig. 5. The recorded wedge opening displacement and the crack growth data were used to drive a finite element model of the alumina wedge-loaded double-cantilever beam (WL-DCB) specimen in its generation mode from which the crack bridging force and the crack growth resistance curve were extracted through an inverse process by matching the measured and recorded crack opening displacements as shown in Figure 6. The dissipated energy in the FPZ was also computed, as expected, were found to be in excess of 99 percent of the energy released during stable crack growth as shown in Figure 7.

High-temperature fracture analysis with the Innova 308 Argon-Ion Laser will be undertaken during this academic year.

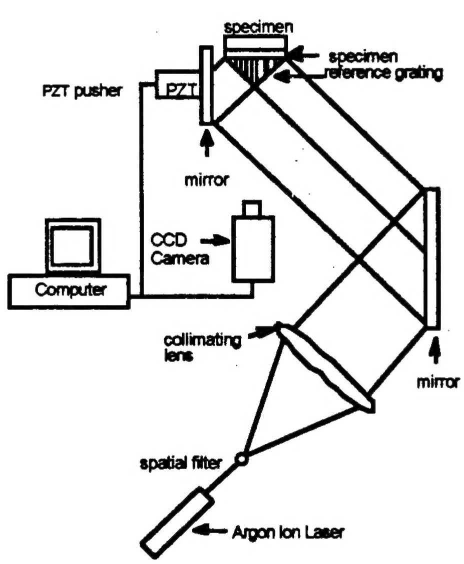


Fig. 4 Phase shifting Moiré interferometry setup

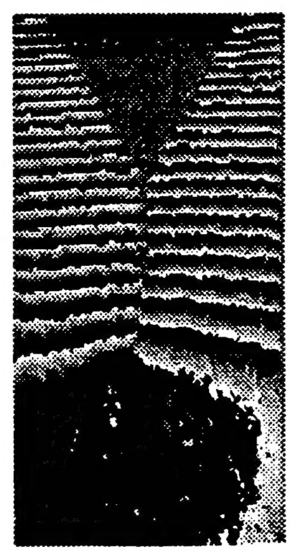
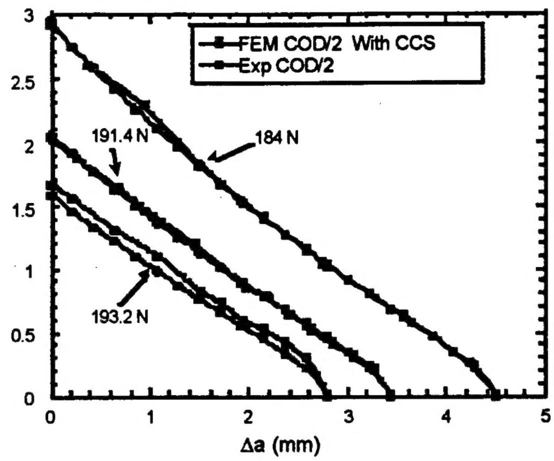


Fig. 5 Phase shifting Moiré pattern of alumina specimen



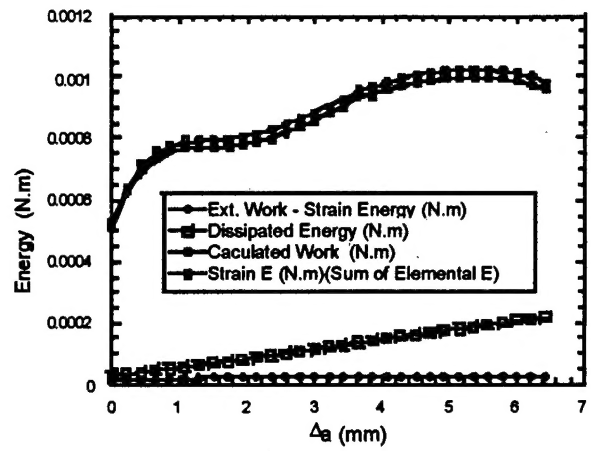


Fig. 6 COD profile vs crack extension of alumina

Fig. 7 Energy vs crack extension of alumina

Conclusion

A new high temperature testing system was designed with the following features:

1. Fast heating/cooling capability without affecting the grips and surrounding parts.

2. Specimen can be tested under tension or compression, and by some modifications of the grip mounting unit, bending tests can also be performed in air, vacuum or inert gas environment.

3. Vertical displacement of a specimen can be measured by laser interferometry system with 8 watt Argon laser.

4. Several calibrating works remain to be made to make this system operable under designed loading.

5. Multiple users both on campus and off campus are expected to use this system in addition to the current PI (Taya) and Co-PIs (Kobayashi and Jenkins).

Table of Contents